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This is a final report on the research carried out under the ARO contract DAAL03-89-K-0036 (ARO proposal number 26015-PH) from April 15, 1989 to August 31, 1992. It describes briefly three accomplishments in the area of resonant tunneling through double-barrier devices made of GaAs/AlGaAs heterostructures. They include results on: (1) magnetotunneling characteristics, (2) noise characteristics, and (3) resonant tunneling from a two-dimensional electron system into one-dimensional subbands of a quantum wire, realized through a novel growth geometry.

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ELECTRON TRANSPORT IN HETEROJUNCTION SUPERLATTICES

FINAL REPORT

D.C. Tsui & M. Shayegan

May 9, 1995

U.S. ARMY RESEARCH OFFICE

Contract DAAL03-89-K-0036
(ARO Proposal No. 26015-PH)

Princeton University

Department of Electrical Engineering

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Electron transport in heterojunction superlattices

Following our work performed under a previous ARO contract, which included the first experimental demonstration of the importance of many-electron effect in transport through double-barrier resonant tunneling structures and observation of an intrinsic electrical bistability, we concentrated on several new aspects of tunneling through such structures:

1. Magnetotunneling characteristics

We made measurements of the current-voltage characteristics of an asymmetric GaAs/Al_xAs double-barrier resonant-tunneling device in a magnetic field **B** parallel to the tunneling direction. In the resonant-tunneling regime the magnetic field induces weak steplike features in the *I(V)* curve and sawtooth oscillations in the *I(B)* curve that are periodic in inverse field. We explain these magnetotunneling features by Landau quantization of the three-dimensional states in the emitter and the two-dimensional states in the well, which induces steplike structure in the tunneling supply function. The experimental *I(V,B)* line shape is in good agreement with self-consistent numerical calculations.

We also made measurements on the magnetotunneling characteristics of a high-quality bistable double-barrier resonant tunneling device in magnetic fields transverse to the tunneling direction. The transverse magnetic field $B_\perp$ causes complex, non-monotonic shifts in the position of the resonant current peak in the *I(V)* curve. The resonant peak is also strongly broadened by $B_\perp$, and the peak current is suppressed. The intrinsic bistability of the device is quenched for $B_\perp > 5$ T. We explain these

effects by invoking the magnetic-field-induced change in transverse momentum Δk as electrons tunnel into the well. The change Δk alters both the tunneling supply function and the tunneling probability for a given alignment of the resonant subband and the emitter electrode. Self-consistent calculations based on this model reproduce the complex behavior of resonant peak position and explain the experimentally observed magnetic-field effects.

2. Noise characteristics

The noise characteristics of the double-barrier resonant-tunneling structures depend on the degree of phase coherence of the tunneling of electrons through the two barriers. We made measurements of the noise characteristics of double-barrier resonant-tunneling structures and systematically studied the behavior of noise on three samples with different barrier structures. Our results provide direct evidence of incoherent tunneling and can be qualitatively understood if phase incoherence of the tunneling processes is taken into account.

3. Resonant tunneling of two-dimensional electrons into one-dimensional subbands of a quantum wire

In the standard experimental system commonly employed in research on double-barrier resonant-tunneling structures the tunneling occurs from a three-dimensional density of states in the emitter into two-dimensional subbands confined by the double-barrier potential.

To study tunneling phenomenon in a novel geometry, we employed liquid-phase epitaxy regrowth on the edge of *in situ* cleaved substrates to create a vertical two-

dimensional electron gas in a double-barrier tunneling potential. Resonant tunneling of two-dimensional electrons through one-dimensional quantum wire subbands was unambiguously identified by negative differential resistance features in the transport characteristics. The bias positions of these features agree with simple tunneling theory estimates based on conservation laws and the calculated band alignment in the structure under bias.

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